

# **Update on the Algorithmic Basis and Predicted Performance of Selected VIIRS Environmental Data Records**

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# Overview

- VIIRS Cloud Mask (VCM)
- Sea Surface (Skin) Temperature
- Land Surface Temperature
- Summaries and Conclusions

# VCM Requirements

Paragraph Number	Solar Conditions/ Cloud Optical Thickness	NPOESS System Requirement
40.4.2-17a	1. Day, Ocean, OD = 0.5 or Less	92%
40.4.2-17b	2. Day, Ocean, OD > 0.5	99%
40.4.2-17c	3. Day, Land, OD = 1 or Less	85%
40.4.2-17d	4. Day, Land, OD > 1	93%
40.4.2-17e	5. Night, Ocean, OD = 0.5 or Less	90%
40.4.2-17f	6. Night, Ocean, OD > 0.5	96%
40.4.2-17g	7. Night, Land, OD = 1 or Less	85%
40.4.2-17h	8. Night, Land, OD > 1	90%
40.4.2-18	p. Degraded Conditions: sun glint area	Night Performance
40.4.2-19	q. Exclusion Conditions: Aerosol optical thickness > 1.0	

**VCM requirements are the most stringent of any operational sensor flown by US**

# VIIRS Designed to Meet VCM Requirements

(Table 2 Hutchison et al., 2005)

VIIRS Channel	Band Center and Width ( $\mu\text{m}$ )	Heritage Sensor	VIIRS Enhancement	Value to VIIRS Cloud Mask Algorithm
M1	0.412/0.020	MODIS Channel 8 SeaWifs Channel 1	Dual Gain	Will not saturate in presence of clouds
I1 M5	0.640/0.080 0.672/0.020	MODIS Channel 1 MODIS Channel 13 AVHRR Channel 1 OLS LF	More accurately calibrated compare to AVHRR/OLS	Calibration provides more accurate analyses
I2 M7	0.865/0.039 0.865/0.039	MODIS Channel 2 MODIS Channel 16 AVHRR Channel 2	More accurately calibrated compare to AVHRR/OLS with more narrow bandpasses than AVHRR	Calibration provides more accurate analyses and narrow bandpasses reduce atmospheric attenuation due to water vapor
M9	1.378/0.015	MODIS Channel 26	Bandpass 50% more narrow	Reduces surface contamination
I3 M10	1.610/0.060 1.610/0.060	MODIS Channel 6 AVHRR Channel 3A	375 m in I3	Provides more accurate snow mask

# VIIRS Designed to Meet VCM Requirements [cont.]

<b>VIIRS Channel</b>	<b>Band Center and Width (μm)</b>	<b>Heritage Sensor</b>	<b>VIIRS Enhancement</b>	<b>Value to VIIRS Cloud Mask Algorithm</b>
I4 M12	3.740/0.380 3.700/0.180	MODIS Channel 20 AVHRR Channel 3B	375 m in I4	Reduces impacts from sub-pixel cloud
M13	4.050/0.155	MODIS Channel 23	750 m	Reduces impacts from sub-pixel cloud
M14	8.550/0.300	MODIS Channel 29	750 m	Reduces impacts from sub-pixel cloud
M15	10.763/1.00	MODIS Channel 31 AVHRR Channel 4	750 m	Reduces impacts from sub-pixel cloud
I5	11.450/1.90	OLS TF	Highly Calibrated 375 m in I5	Reduced impacts from sub-pixel cloud
M16	12.013/0.95	MODIS Channel 32 AVHRR Channel 5	750 m	Reduced impacts from sub-pixel cloud
DNB	0.7/0.4	OLS DNB	Accurately calibrated	Not used currently

# VCM Cloud Tests Exploit The VIIRS Design

Cloud Tests	Water	Land	Desert	Coast	Snow
1. M9 (1.38 $\mu\text{m}$ ) Reflectance Test	X	X	X	X	X
2. M15-M16 (10.76 – 12.01 $\mu\text{m}$ ) Brightness Temperature Difference (BTD)	X	X	X	X	
3. M15 (10.8 $\mu\text{m}$ ) Brightness Temperature (BT) Test	X				
4. M12-M16 (3.70–10.76 $\mu\text{m}$ ) BTD Test					
5. Tri-Spectral M14, M15, M16 ( 8.55, 10.76, 12.01 $\mu\text{m}$ ) BTD Test	X				
6. M15-M12 (10.76-3.70 $\mu\text{m}$ ) BTD Test	X (if no sun glint)	X	X (if Lat > 60° or < - 60°)	X (if no sun glint)	X
7. M12-M13 (3.70-4.05 $\mu\text{m}$ ) BTD Test	X (if -60° < Lat < 60°)	X (if -60° < Lat < 60°)	X	X	X (if -60° < Lat < 60°)

**This set of cloud tests follow closely heritage MODIS cloud mask algorithm**

# VCM Cloud Tests Exploit VIIRS Design [ cont.]

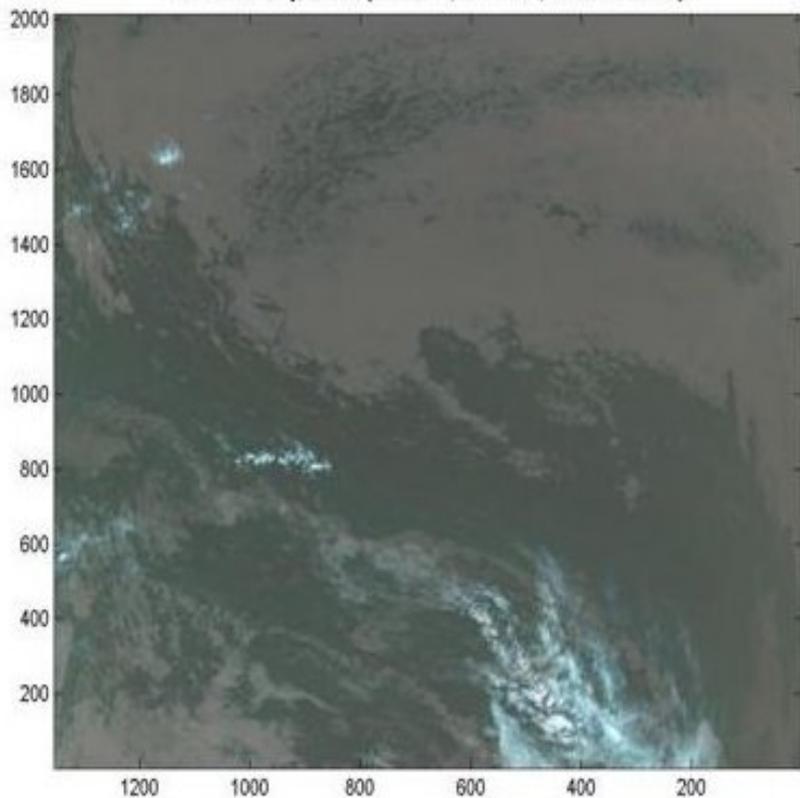
Cloud Tests	Water	Land	Desert	Coast	Snow
8. M5 (0.672 $\mu\text{m}$ ) Reflectance Test as a function of NDVI - switching to M1 (0.405 $\mu\text{m}$ ) if NDVI < 0.2		X		X	
9. M7 (0.865 $\mu\text{m}$ ) Reflectance Test	X				
10. M7/M5 (0.865 / 0.672 $\mu\text{m}$ ) Reflectance Ratio Test	X	X Requires M5 Reflect. > 0.10			
11. M1 (0.412 $\mu\text{m}$ ) Reflectance Test			X		
12. I4 (3.74 $\mu\text{m}$ ) Spatial Test					
13. I5 (11.45 $\mu\text{m}$ ) Spatial Test	X				
14. I2 (0.865 $\mu\text{m}$ ) Reflectance Test	X				

**Implementation of Test 8 and Tests 11-14 are unique to VCM Algorithm**

# Results

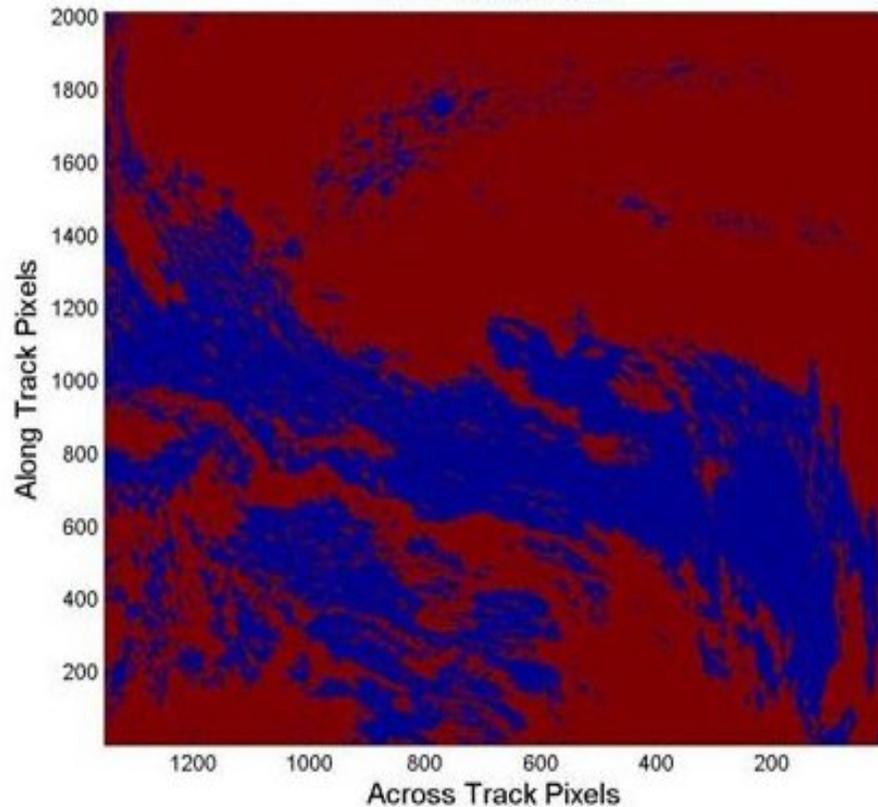
MOD2001.032.0435

Color Composite (BTM12, BTM14, and BTM15)



Color composite

Truth Cloud mask

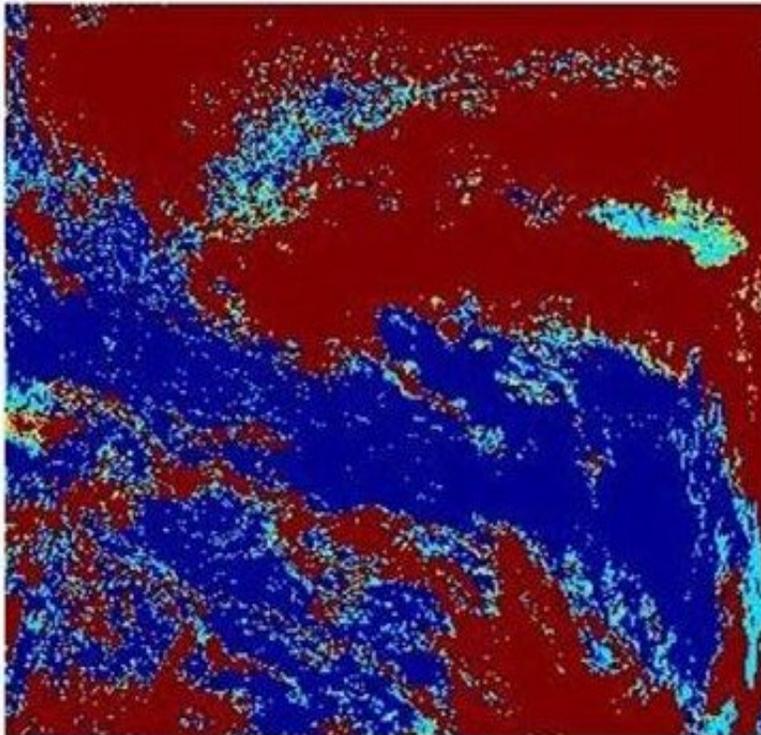


Manually-generated cloud mask

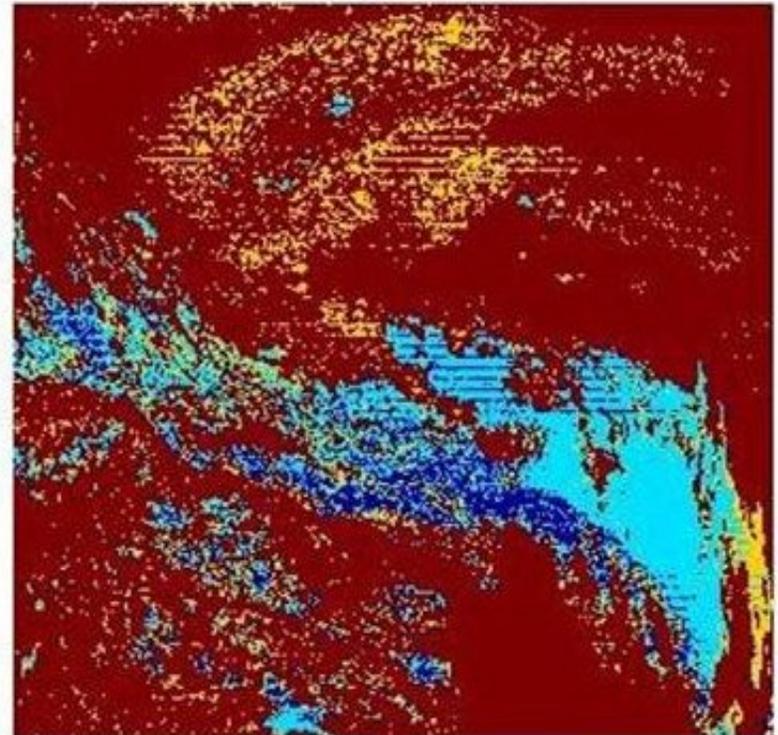
# VIIRS vs MODIS Cloud Mask

MOD2001.032.0435

VCM Cloud Confidence

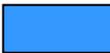


Modis Cloud Confidence



VIIRS cloud mask

MODIS cloud mask

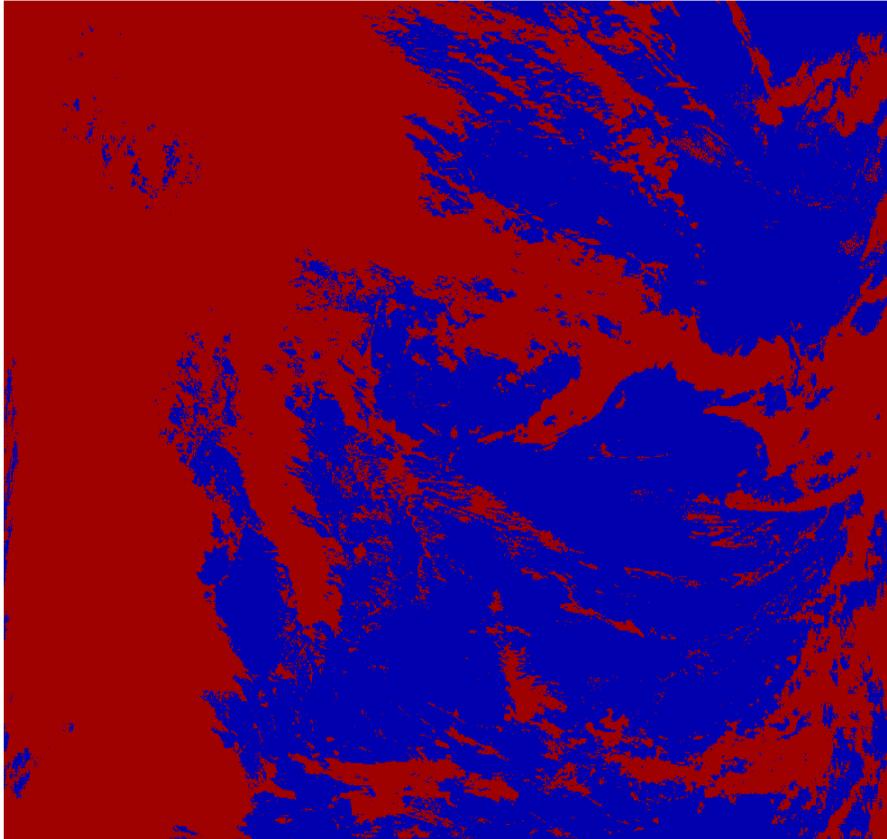
 Confidently Clear  
 Probably Clear

 Confidently Cloudy  
 Probably Cloudy

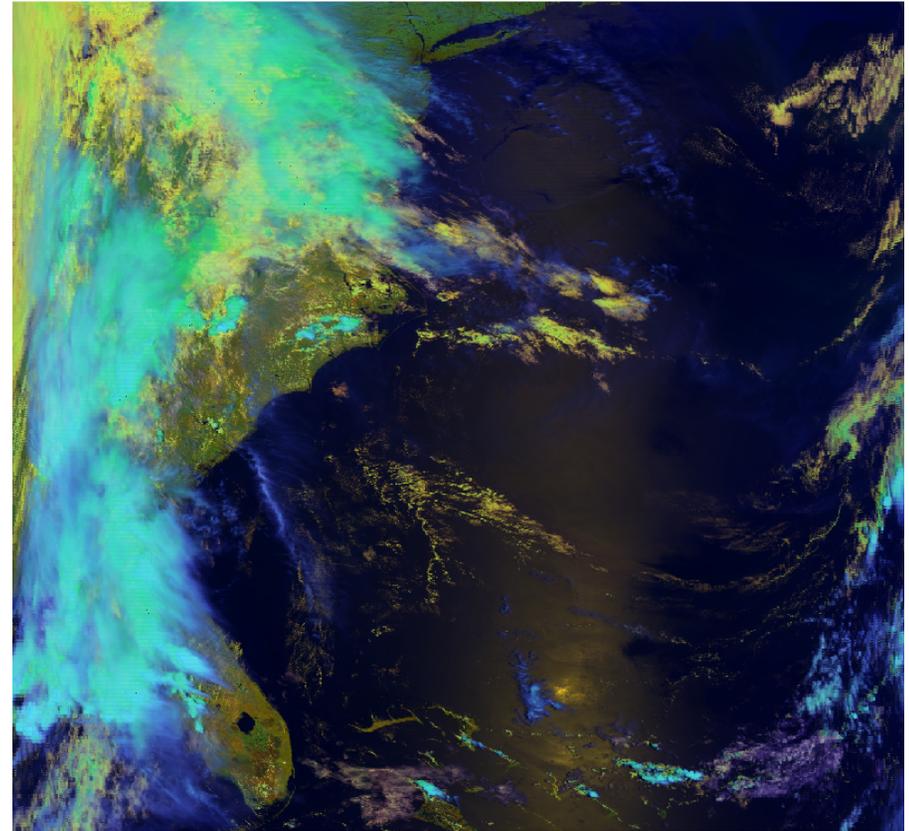
# Results

## MOD2001.152.1600

VIIRS Manual Cloud Mask



VIIRS Color Composite [M10 M07 1-M15] 2001152\_1600

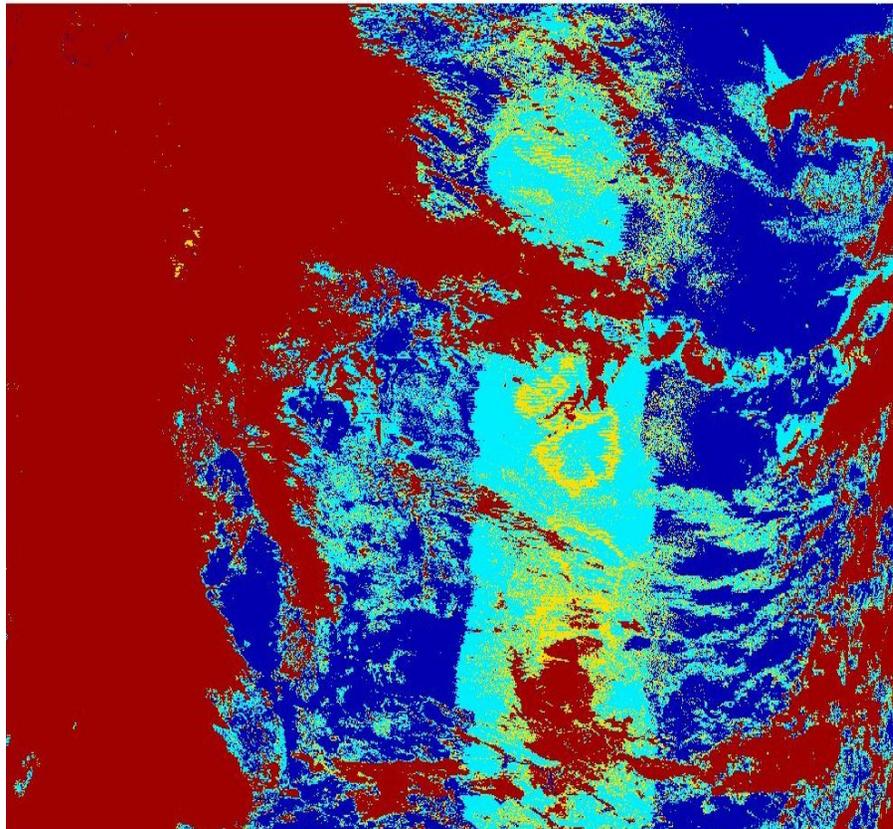


**Multi-layered clouds with sunglint over gulfstream region of US Atlantic Coast**

# VIIRS Cloud Mask and Phase

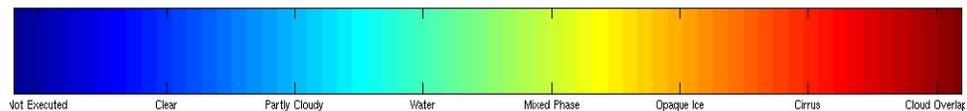
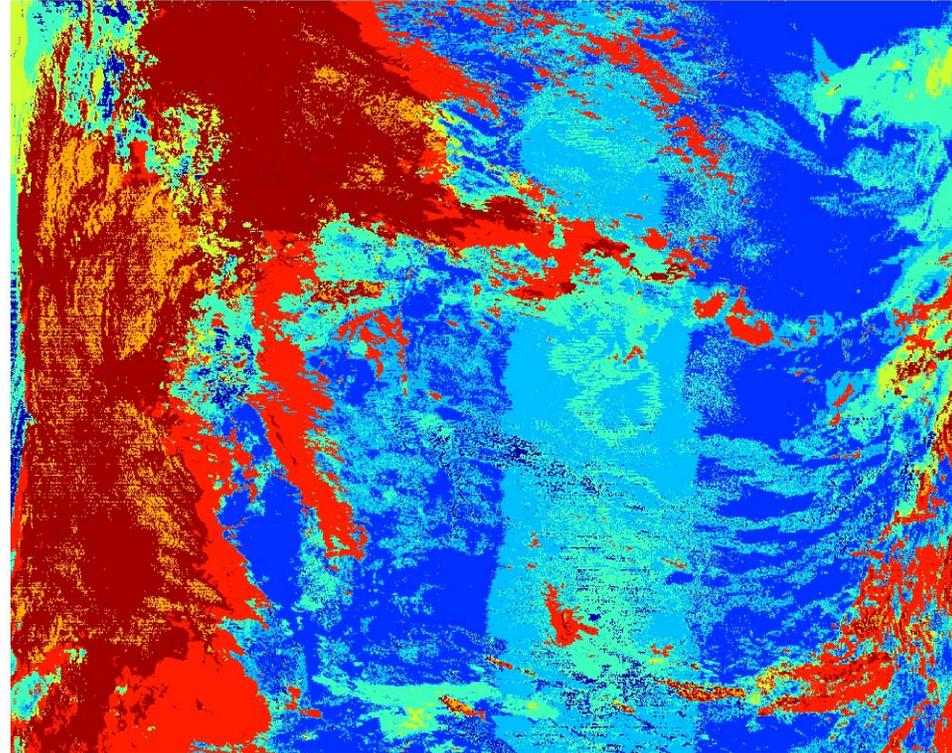
MOD2001.152.1600

VIIRS Cloud Mask



VIIRS cloud mask

VIIRS Cloud Phase



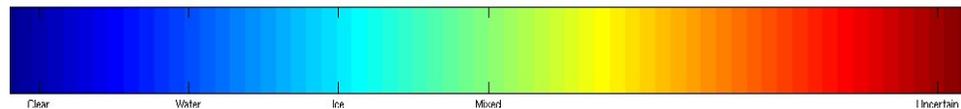
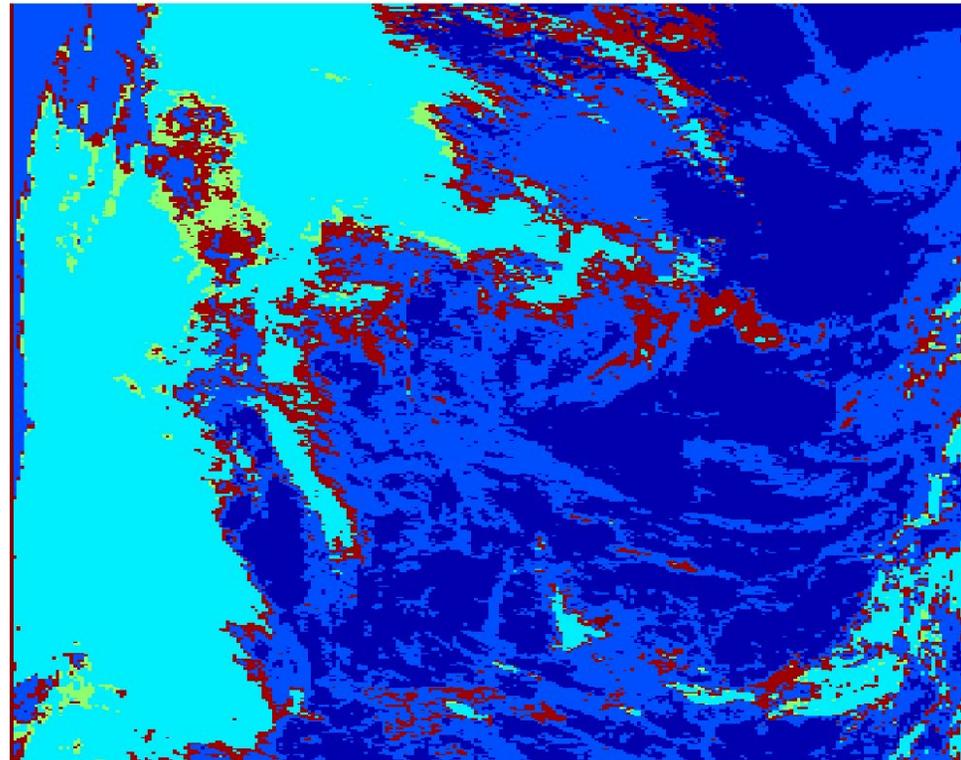
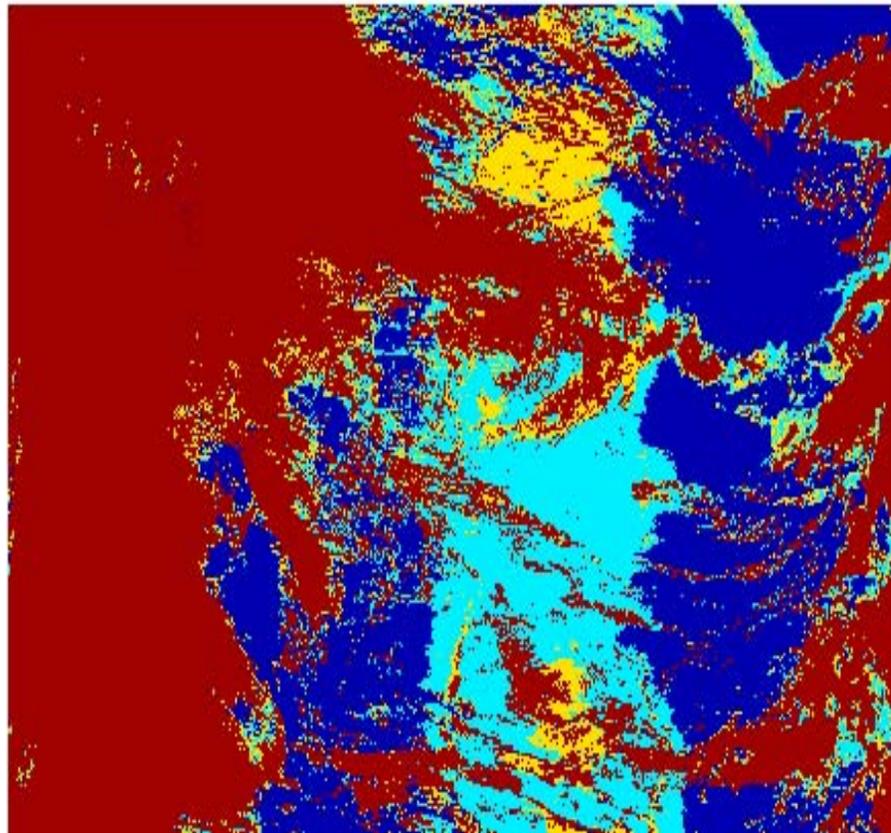
VIIRS cloud phase (1-km)

# MODIS Cloud Mask and Phase

MOD2001.152.1600

Modis Cloud Mask

Modis Cloud Phase



MODIS cloud mask

MODIS cloud phase (5-km)

# Summary

## VIIRS Cloud Mask

- VIIRS and MODIS Cloud Masks are Very Comparable
  - MODIS mask tends to have more clouds than VCM
  - Differences are noted in detection of thin cirrus in sunglint regions
  - VCM IR spatial test not able to be effectively applied since MODIS lacks IR imagery resolution bands
- VIIRS Cloud Phase Appears to Provide a High-Quality Pixel-Level While MODIS Produces an Aggregated (5-km) Product

# VIIRS SST Requirements

Paragraph	Subject	Specified Value
	a. <b>*Horizontal Cell Size</b>	
40.2.4-3	1. <b>*Nadir, Clear</b> [VIIRS Guarantee]	<b>0.75 km</b>
40.2.4-4	2. Worst Case, Clear [VIIRS Guarantee]	1.3 km (HCS at CMIS Swath)
40.2.4-5	b. Horizontal Reporting Interval [VIIRS & CMIS Guarantee]	HCS
40.2.4-23	c. Horizontal Coverage [VIIRS & CMIS Guarantee]	Oceans
40.2.4-8	d. Measurement Range [VIIRS & CMIS Guarantee]	271 K – 313 K
	e. Measurement Uncertainty (Skin)	
40.2.4-9a	1. <b>* Clear, Favorable Conditions</b> [VIIRS Guarantee]	<b>0.35 K</b>
40.2.4-9b	2. <b>* Clear, Not Favorable Conditions</b> [VIIRS Guarantee]	<b>0.5 K</b>
40.2.4-10	f. Measurement Uncertainty (Bulk)	0.5 K
	g. Measurement Precision (Skin)	
40.2.4-11a	1. Clear, Favorable Conditions [VIIRS Guarantee]	0.27 K
40.2.4-11b	3. Clear, Not Favorable Conditions [VIIRS Guarantee]	0.45K

# VIIRS SST Requirements

## [cont.]

Paragraph	Subject	Specified Value
	h. Mapping Uncertainty, 3 Sigma	
40.2.4-12	1. Nadir, Clear [VIIRS Guarantee]	0.4 km
40.2.4-13	2. Worst Case, Clear [VIIRS Guarantee]	1.5 km
	i. Maximum Local Average Revisit Time	
40.2.4-16a	1. Clear [VIIRS, Reduced Swath Width]	5.8 hrs
	j. Measurement Precision (Bulk, Clear)	
40.2.4-17a	1. Clear, Favorable Conditions [VIIRS Guarantee]	0.27 K
40.2.4-17b	2. Clear, Not Favorable Conditions [VIIRS Guarantee]	0.45K
40.2.4-21	k. Long Term Stability (C) [VIIRS]	0.1 K
	o. Clear Measurement Uncertainty Exclusion Conditions [VIIRS Exclusions]	
40.2.4-26a	1. Aerosol Optical Thickness > 1.0	
40.2.4-26b	2. Within 3 milliradian of an Area 12 km x 12 km or Greater that is At Least the Maximum VIIRS Radiance	

# SST Definitions

## Favorable Conditions

- Clear AND
- SST < 285 K AND
- Sensor Zenith Angle <= 40 degrees AND
- Aerosol Optical Thickness <= 0.2 Tau

## Unfavorable Conditions

- Clear AND
- SST >= 285 K OR
- Sensor Zenith Angle > 40 degrees AND
- Sensor Zenith Angle <= 50.3 degrees OR
- Aerosol Optical Thickness > 0.2 Tau AND <= 1.0 Tau

# VIIRS (Skin) SST Algorithms

## VIIRS Daytime algorithms:

Dual split window (10.8, 12, 3.7, 4.0  $\mu\text{m}$  bands)

$$SST = a_0 + a_1 T_{11} + a_2 T_{12} + a_3 (\sec(z) - 1) + a_4 T_{3.7} + a_5 T_{4.0} + a_6 T_{3.7} \cos(zs) + a_7 T_{4.0} \cos(zs) + a_8 (T_{11} - T_{12})^2$$

Alternative Split window (10.8 + 12  $\mu\text{m}$  bands)

$$SST = a_0 + a_1 T_{11} + a_2 (T_{11} - T_{12}) + a_3 (\sec(z) - 1) + a_4 (T_{11} - T_{12})^2$$

**VIIRS Nighttime algorithm:** Dual split window (10.8, 12, 3.7, 4.0  $\mu\text{m}$  bands)

$$SST = a_0 + a_1 T_{11} + a_2 T_{12} + a_3 (\sec(z) - 1) + a_4 T_{3.7} + a_5 T_{4.0} + a_6 T_{3.7}^2 + a_7 T_{4.0}^2 + a_8 (T_{11} - T_{12})^2$$

- Stratified by day/night as well as four temperature/moisture regimes.
  - Cold/warm stratification defined by a  $T_{11}$
  - Warm stratification divided into three moisture stratifications based upon  $T_{11} - T_{12}$  feature

# MODIS (Skin) SST Algorithms

**Daytime:** Non-linear split window (10.8 and 12  $\mu\text{m}$  bands) - AVHRR heritage

$$SST = c_1 + c_2 T_{31} + c_3 (T_{31} - T_{32}) RSST + c_4 (\sec(z) - 1)(T_{31} - T_{32})$$

**Nighttime:** Non-linear split window (10.8 and 12  $\mu\text{m}$  bands) - AVHRR heritage

$$SST = c_1 + c_2 T_{31} + c_3 (T_{31} - T_{32}) + c_4 (\sec(z) - 1)(T_{31} - T_{32})$$

: Also 4.0  $\mu\text{m}$  algorithm (3.9 & 4.0  $\mu\text{m}$  bands) – MODIS specific

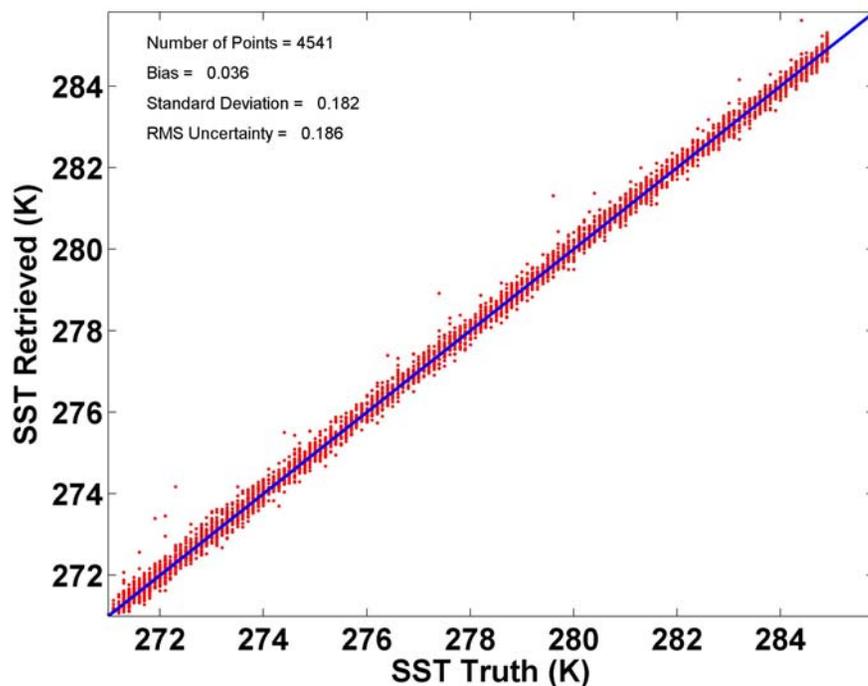
- Stratified by day/night as well as 2 temperature/moisture regimes.
  - Divided into two moisture stratifications based upon  $T_{11} - T_{12}$  feature

# VIIRS APU Performance - Favorable Conditions

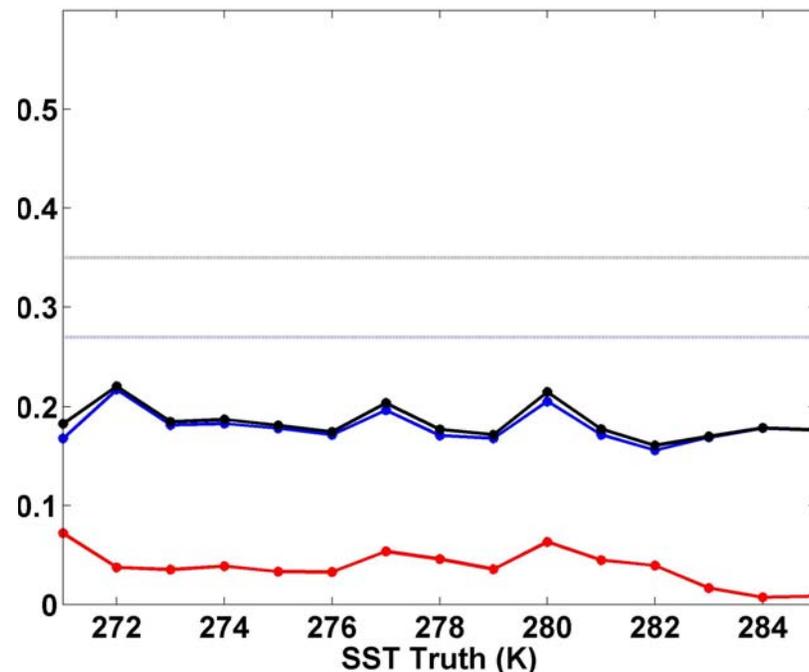
Based upon Global Synthetic Data

Accuracy, Precision, Uncertainty (APU) Predictions for Favorable Conditions

SST Truth vs. Retrieved (VIIRS Skin SST Fav)



SST Binned Quality Attributes (VIIRS Skin SST Fav)

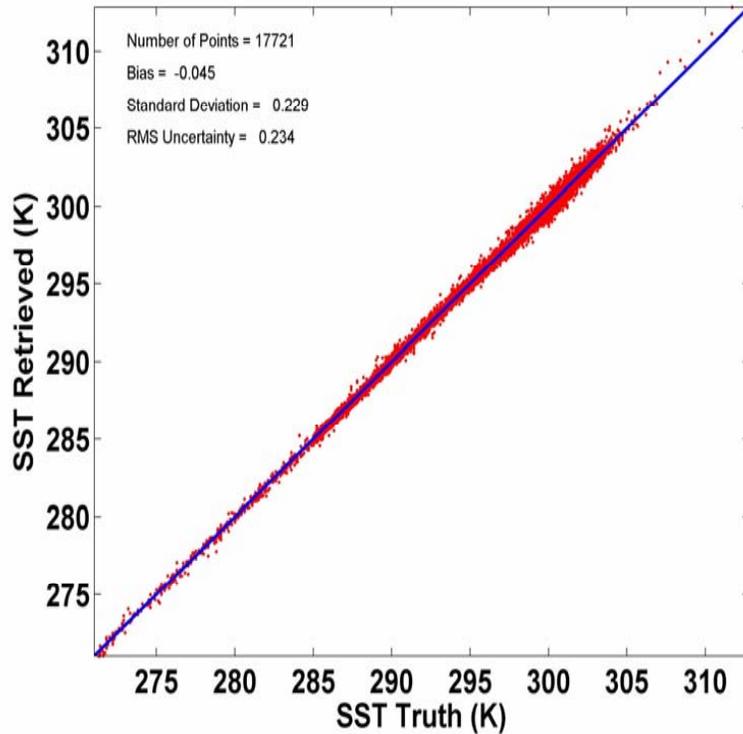


Based upon Global Synthetic Data – see Grano et al. (2004) for details

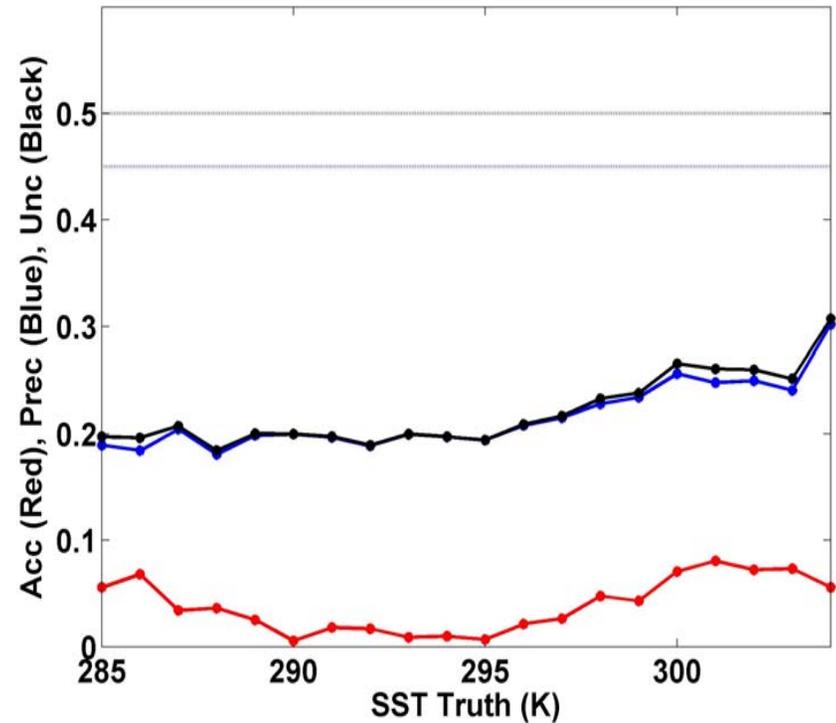
# VIIRS APU Performance – Unfavorable Conditions

Based upon Global Synthetic Data

SST Truth vs. Retrieved (VIIRS Skin SST Unf)

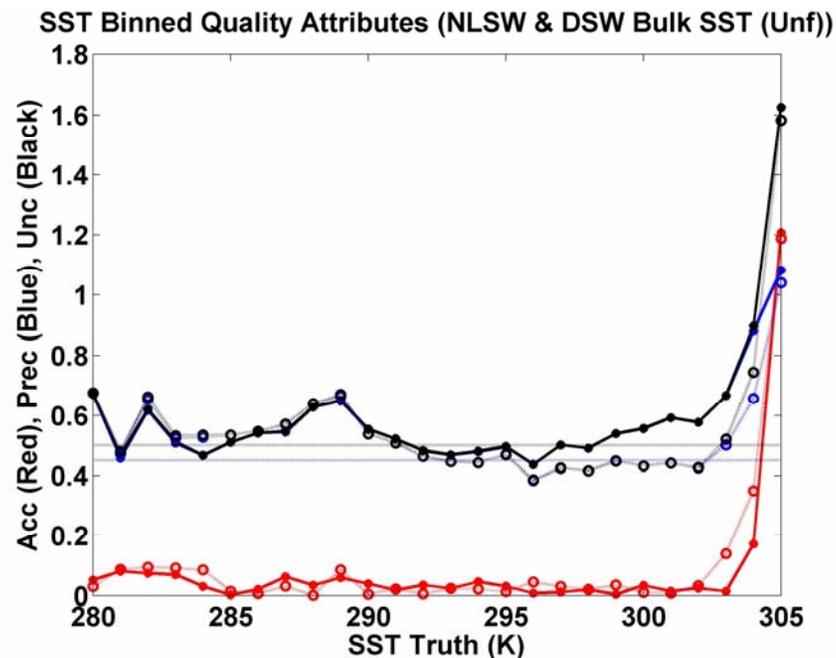
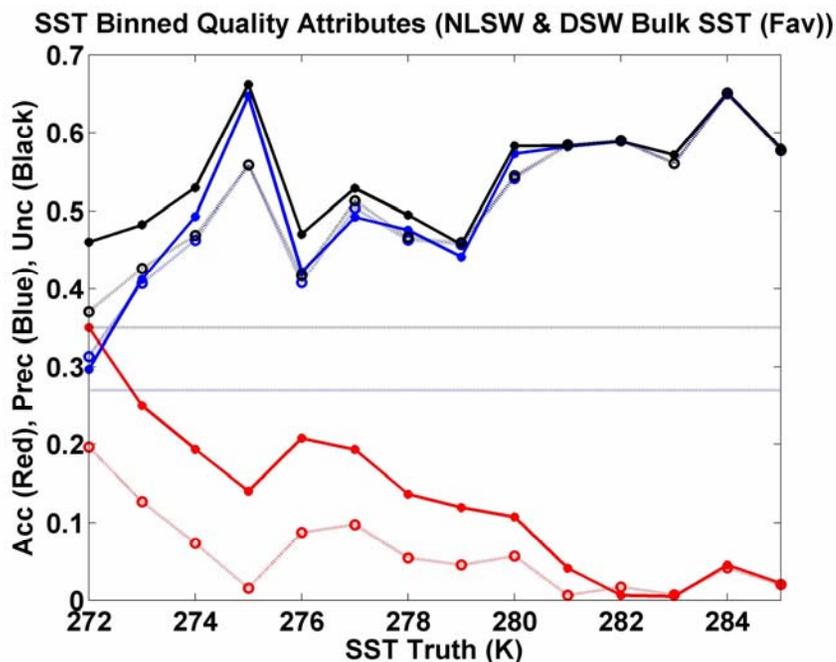


SST Binned Quality Attributes (VIIRS Skin SST Unf)



# APU (Bulk) SST Performance

Based upon MODIS Cal/Val Datasets



— NLSW (MODIS, AVHRR heritage algorithms)  
----- DSW (VIIRS algorithms)

# Summary on SST EDR

- VIIRS Algorithms Expected to Meet System Requirements for Skin SST
- Requirements for Bulk SST Challenging for Entire Measurement Range
  - VIIRS (Bulk) SST algorithms perform slightly better than heritage algorithms
- Predictions Assume a Perfect VIIRS Cloud Mask
  - VIIRS Cloud Mask has been shown to have  $< 1\%$  leakage (undetected clouds) over ocean surfaces
  - Chain testing underway at NGST to assess impacts of VCM on SST APU predictions

# VIIRS LST (Skin) Requirements

Paragraph	Subject	NGST Syst Spec	IORD-II
	a. Horizontal Cell Size		
40.6.1-1	1. Nadir	0.75 km	
40.6.1-12	2. Edge of Swath	1.3 km	
40.6.1-2	b. Horizontal Reporting Interval	HCS	4 km
40.6.1-3	c. Horizontal Coverage	Land	
40.6.1-4	d. Measurement Range	213 K – 343 K	213 K – 343 K
40.6.1-5	e. Measurement Accuracy	2.4 K	2.5 K
40.6.1-6	f. Measurement Precision	0.5 K	0.5 K
40.6.1-7	g. Mapping Uncertainty	1.5 km	4 km
40.6.1-8	h. Max Local Average Revisit Time	5.8 hrs (NPP excl)	6 hours
40.6.1-10	i. Latency	See Appendix E	90 minutes
40.6.1-11	j. Measurement Uncertainty, Nadir	2.5 K	
40.6.1-13	k. Excluded Measurement Condition: AOT > 1.0		

# VIIRS Primary LST Algorithm

- From the VIIRS LST ATBD
- Land Cover regression methods: Establish one dual split window regression equation for each of the 17 IGBP surface types using 4 VIIRS LWIR bands (3.75, 4.0, 11, and 12  $\mu\text{m}$ ), with added solar zenith angle correction during daytime.

- Baseline algorithm, 3.75, 4.0, 11, and 12  $\mu\text{m}$  dual split window:

- $LST(\text{Daytime}) = a_0 + a_1 T_{11} + a_2 (T_{11} - T_{12}) + a_3 (\sec \theta - 1) + a_4 T_{3.75} + a_5 T_{4.0} + a_6 T_{3.75} \cos \phi + a_7 T_{4.0} \cos \phi + a_8 (T_{11} - T_{12})^2$

- $LST(\text{Nighttime}) = b_0 + b_1 T_{11} + b_2 (T_{11} - T_{12}) + b_3 (\sec \theta - 1) + b_4 T_{3.75} + b_5 T_{4.0} + b_6 T_{3.75}^2 + b_7 T_{4.0}^2 + b_8 (T_{11} - T_{12})^2$

# VIIRS Alternative LST Algorithm

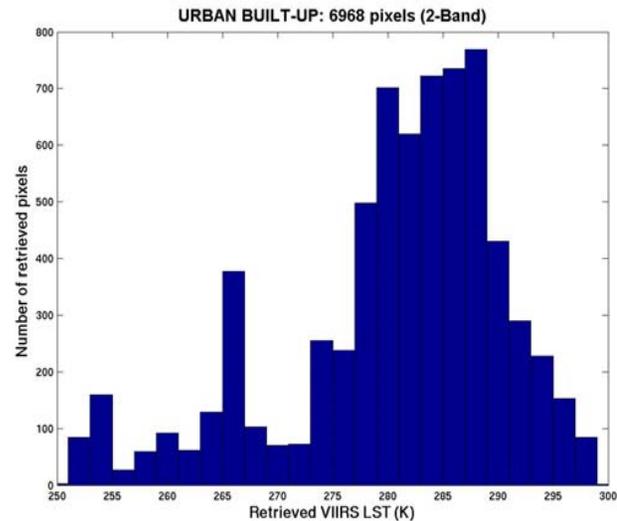
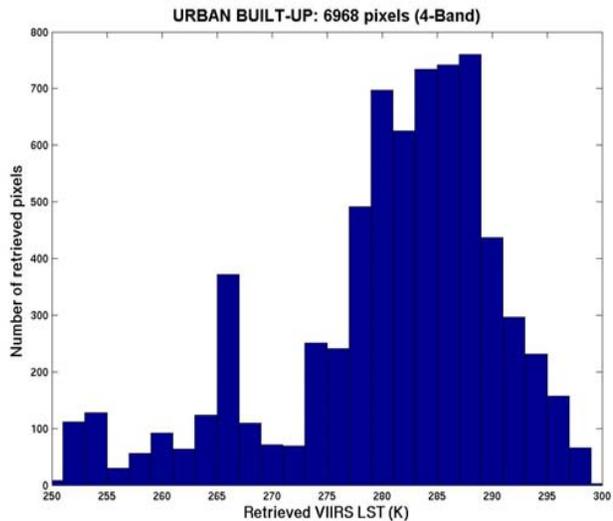
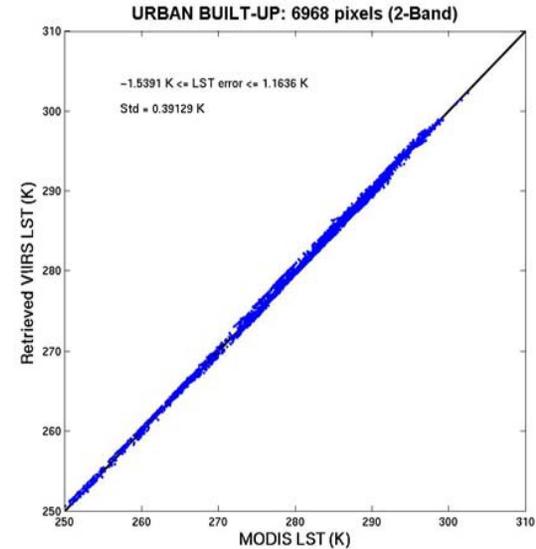
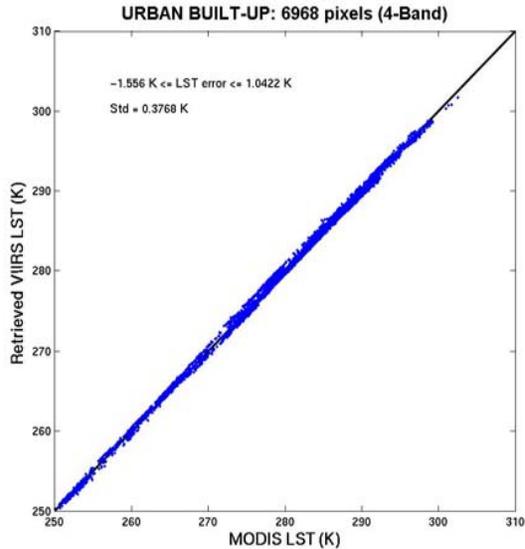
- From the VIIRS LST ATBD
- Revert back to a 2-band (11 and 12  $\mu\text{m}$ ) split window algorithm for both day and night fallback situations (e.g., sun glint and poor quality input).
- Fallback algorithm, 11 and 12  $\mu\text{m}$  dual split window:
- $LST(\text{Daytime}) = c_0 + c_1 T_{11} + c_2(T_{11} - T_{12}) + c_3(\sec\theta - 1) + c_4(T_{11} - T_{12})^2$
- $LST(\text{Nighttime}) = d_0 + d_1 T_{11} + d_2(T_{11} - T_{12}) + d_3(\sec\theta - 1) + d_4(T_{11} - T_{12})^2$

# Performance Based upon MODIS Proxy Data

- Use MODIS data to populated LST regression LUT for 17 IGBP surface types, day and night, 4-band dual split-window and 2-band split window
  - Constructed from 143 day and 128 night MODIS granules
- Limit test data to best quality, clear pixels with expected error  $< 0.5$  K from nadir to 1.3 km
- Train regression coefficients on MODIS pixels identified as  $> 98\%$  pure IGBP types
- Assess VIIRS algorithm performance versus MODIS for each surface type

# VIIRS LST APU for Urban

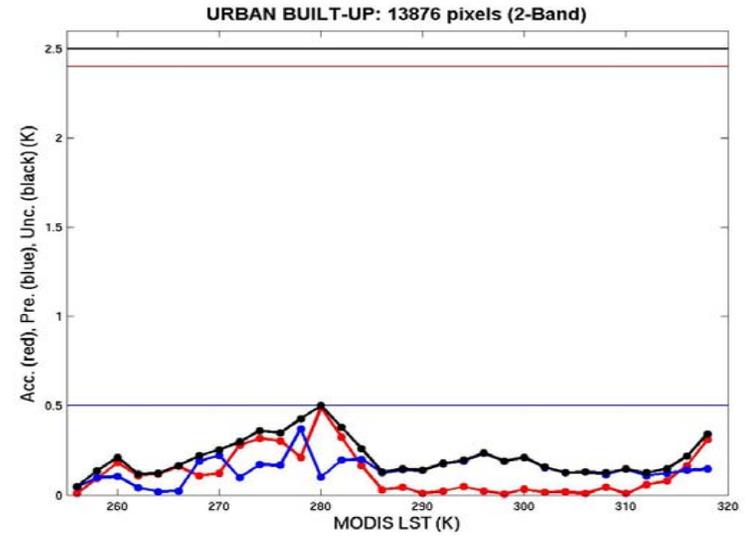
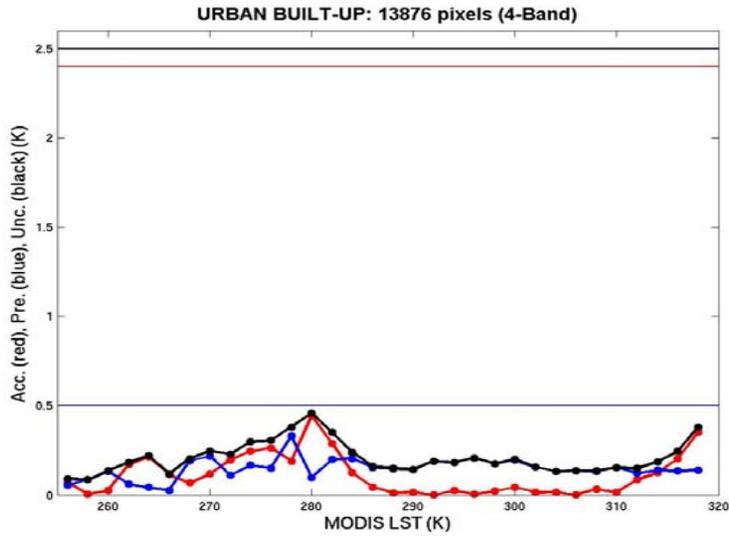
## Compare to MODIS LST Product



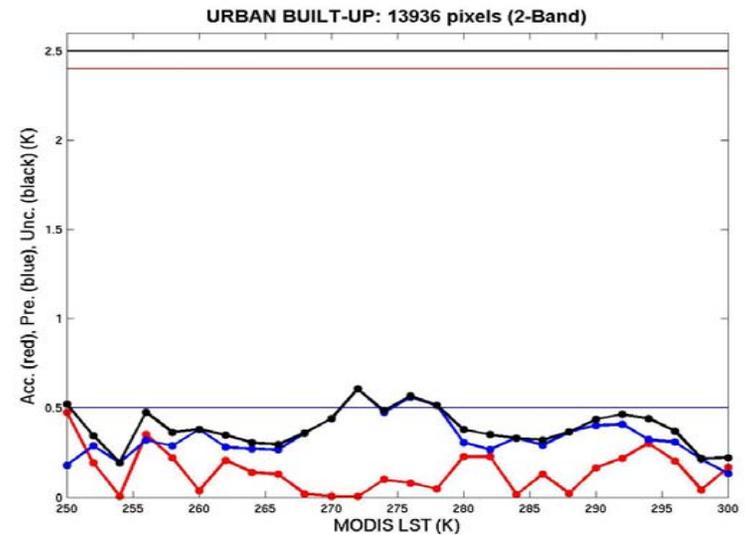
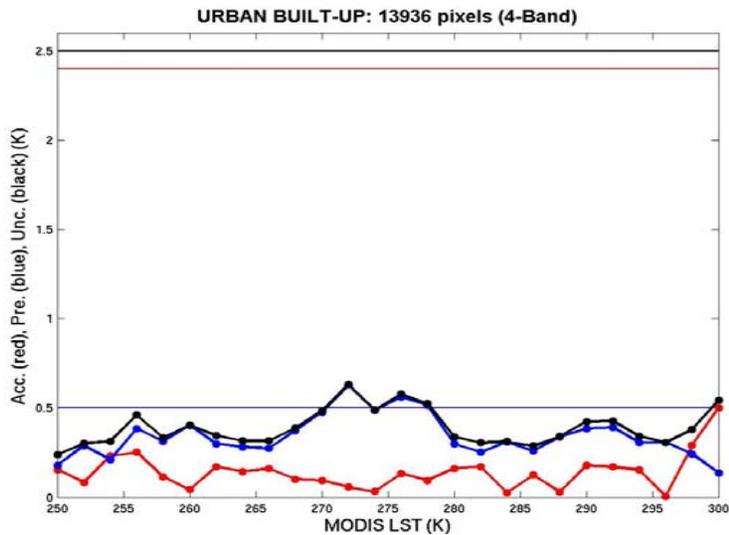
# LST APU

## For > 98% Urban Build-Up

*Day*

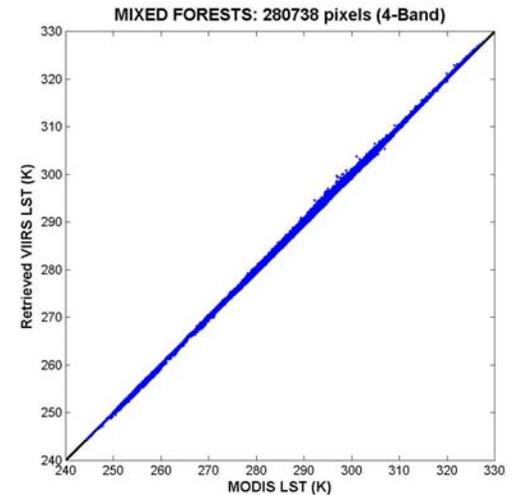
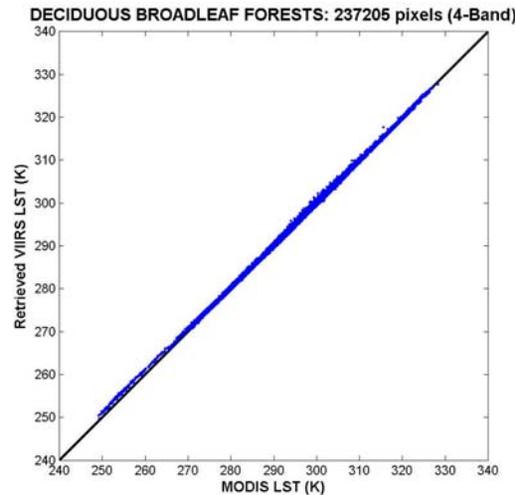
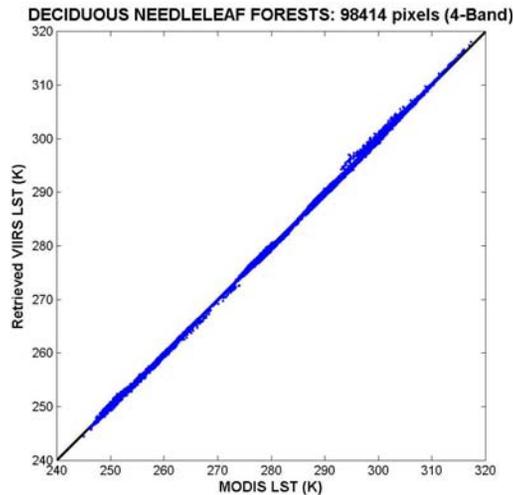
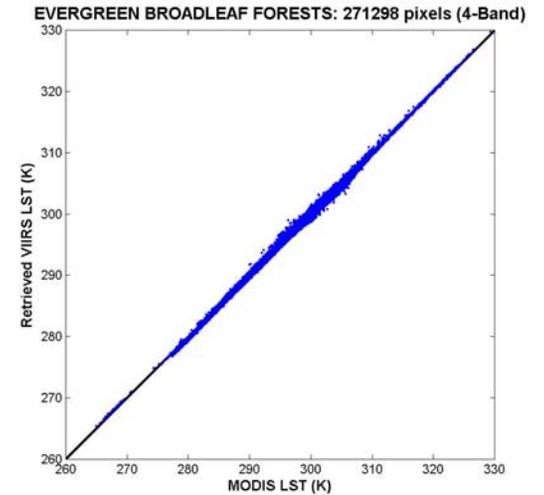
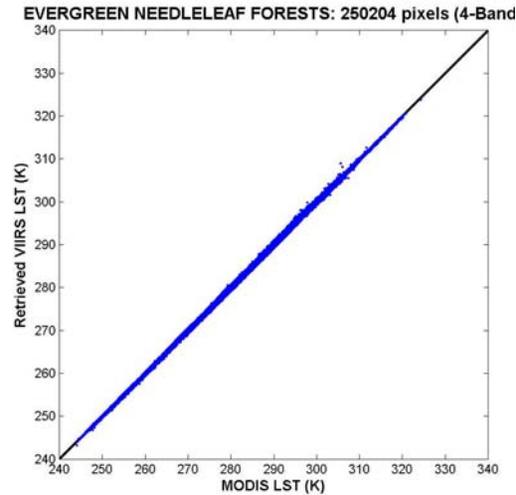
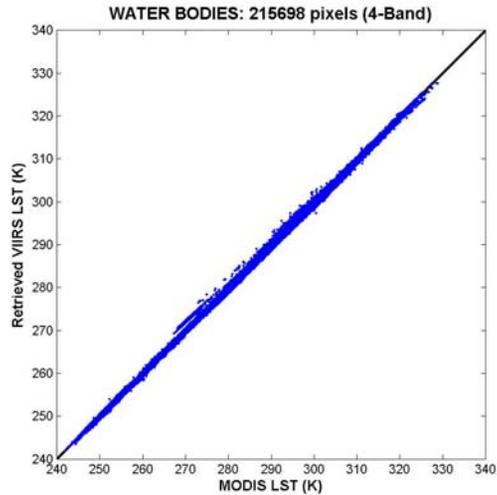


*Night*



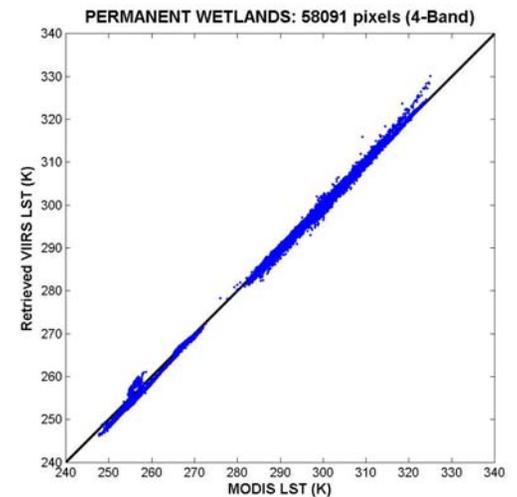
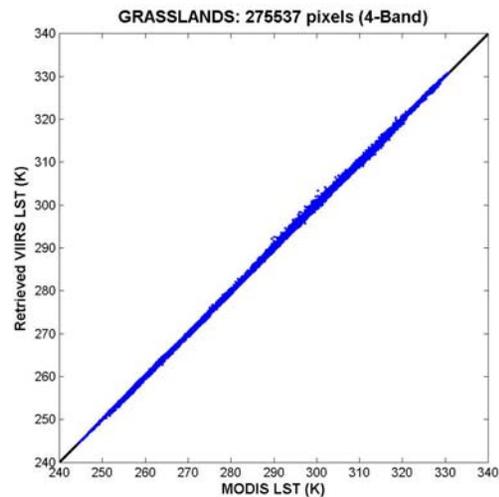
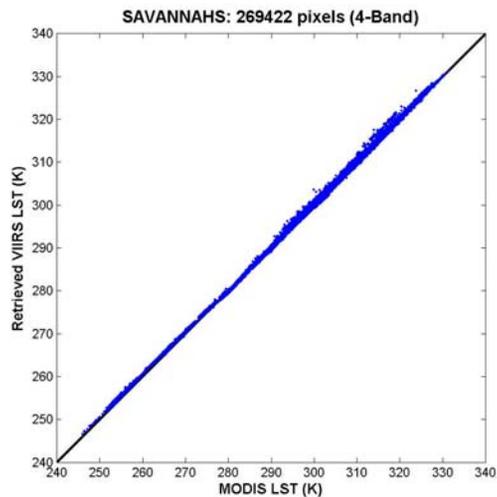
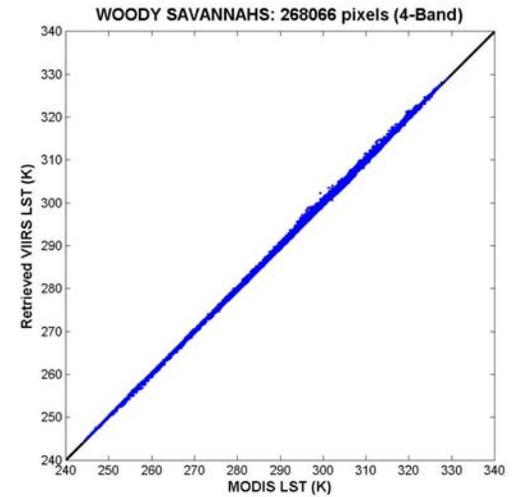
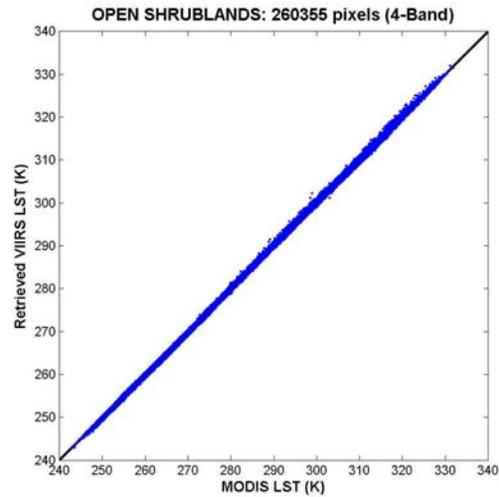
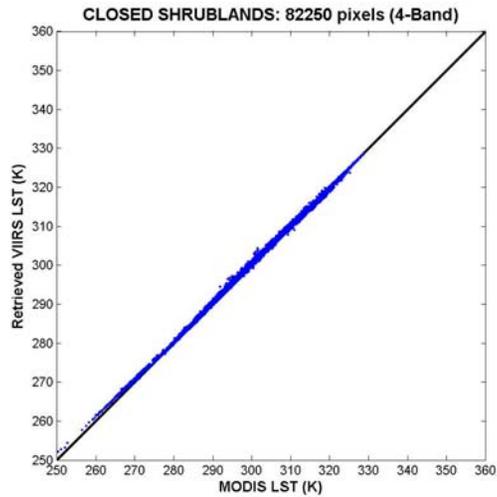
# LST Retrievals on Majority Type

## VIIRS Performance Compared to MODIS LST Product



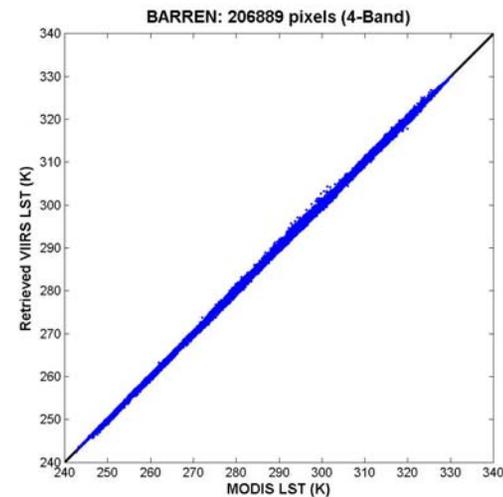
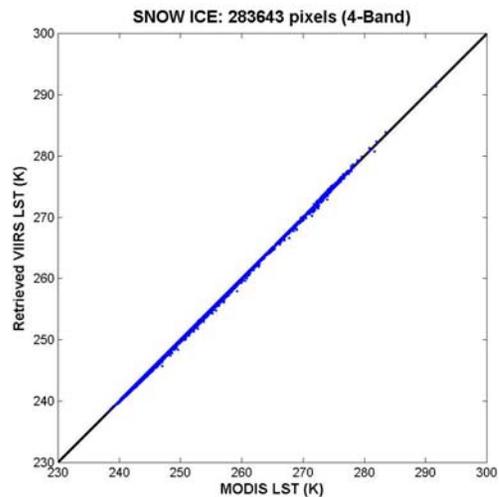
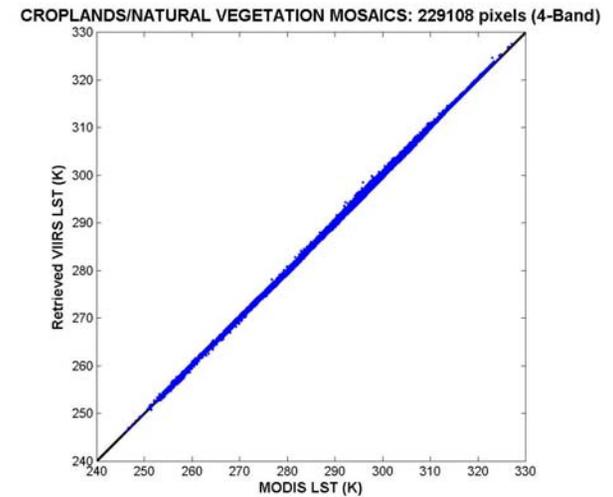
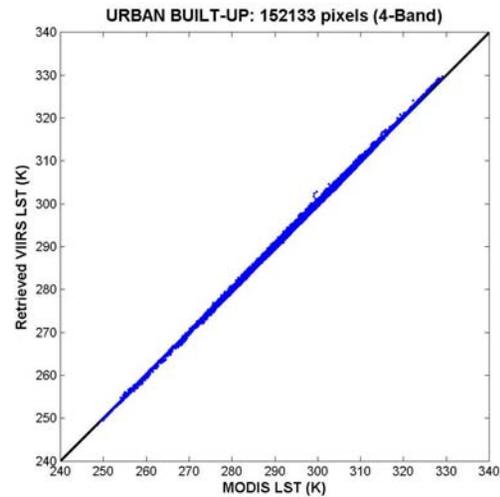
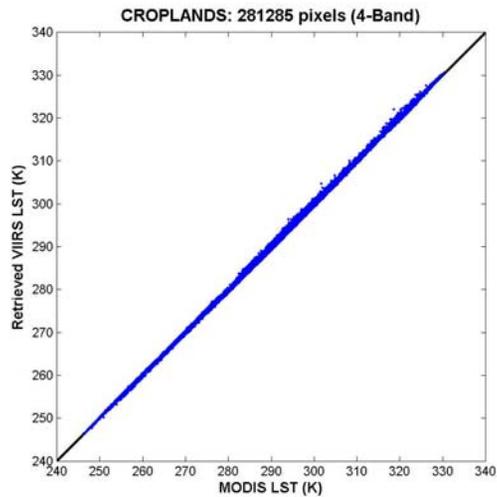
# LST Retrievals on Majority Type

## VIIRS Performance Compared to MODIS LST Product



# LST Retrievals on Majority Type

## VIIRS Performance Compared to MODIS LST Product



# Summary on LST EDR

- Comparisons between MODIS and VIIRS APU are very similar
- LST APU will be assessed during Chain-Testing using global synthetic data with less homogeneous land types